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An assessment of groundwater quality for drinking and agricultural purposes in Ca Mau peninsula, Vietnamese Mekong Delta

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Abstract. Groundwater serves as the major source for drinking water and the only fresh water source in the dry season in Ca Mau province, the Vietnamese Mekong Delta. The study is performed to assess groundwater quality in the area. Groundwater Quality Index (GWQI), magnesium hazard (MH), sodium percentage (Na%), sodium adsorption ratio (SAR), permeability index (PI) combined with geostatistical tools were conducted by using groundwater quality data from 400 samples collected from private wells. GWQI values suggest that 7%, 63%, 28%, 2%, 1% of total samples are classified into excellent, good, poor, very poor and unsuitable for drinking water. High Cl and TDS are the main cause of high GWQI values suggesting that saltwater intrusion deteriorates groundwater quality. For irrigation purposes, 4%, 17%, 36%, 43% of total samples classify into Good, Permissible, Doubtful, Unsuitable respectively by Na% indicator; 55.0%, 30.9%, 11.9%, 2.2% of total samples is Excellent, Good, Doubtful and Unsuitable according to SAR, 54% samples are unsuitable by MH index, and all samples are good by PI. This study provides useful information on groundwater quality for various purposes in Ca Mau province, that could help water management and water users to identify the necessary approach for groundwater protection and water-treatment methods before utilising the groundwater source for specific purposes in the study area.

1. Introduction

Groundwater is widely used over the world as the most important resources for drinking and irrigation purposes in coastal area due to seawater intrusion and pollution of surface water. Lack of water supply system and easily accessible are also the reason for many people prefer using groundwaters. However, groundwater quality is deteriorating due to natural forces such as geochemical, weathering processes, tectonic, and human activities such as overexploitation, urbanisation, fertiliser application [1]. In coastal aquifers, groundwater quality is additionally impacted by seawater level rise and seawater intrusion [2]. Consumption of contaminated drinking water can lead to human health problems [3]. Using poor groundwater quality for irrigation can also cause adverse impacts on soil, plant, and production yield [4, 5].

Assessment of groundwater quality suitability for various purposes of water uses are important for managers, planners, policy makers and user to address appropriate solutions to groundwater management and protection either technological treatment or alternative water resources for avoiding the adverse effects on human health and the environments [6]. Poor groundwater quality may be caused by a single or multiple (bio)chemical elements that concentrations exceed the recommendations for using such as drinking or irrigation water quality. It is difficult to directly stack the pollution effects brought by different elements due to the different dimensions of elements. Moreover, information about groundwater quality also needs to be reported in a simple language and understandable manner for different stakeholders in practices. Therefore, integrated index methods such as groundwater quality index (GWQI) is widely used for evaluation of groundwater quality for drinking purpose [6]. The GWQI method standardises different indicators and then converts them into a single value. This makes it easy to express the comprehensive influence of various indices on groundwater and facilitate the comparison between samples collected from different regions. GWQI has been applied as an effective approach to communicate water quality information to decision makers and is widely used in many areas such as India [7], Iran [8], Palestine [9], USA [10]. The Geographic Information System (GIS) can support water quality assessment to understand clear picture of spatial variability of groundwater quality. Thus, integration of the GIS and the GWQI can help the decision-maker to take appropriate steps for monitoring and conservation of the groundwater quality for sustainable management of the aquifer system [7].

Groundwater is crucial resources for water supply in Vietnam. Especially, groundwater provides 62% of total water supply for domestic use in Mekong Delta [11]. In Ca Mau Province, groundwater is the only source for drinking water [12]. Over abstraction of groundwater induces negative effects such as land subsidence [13], saltwater intrusion [14]. Even though many groundwater geochemical issues are noticed in other provinces of the Vietnamese Mekong Delta such as groundwater arsenic contamination in An Giang, Dong Thap [14], seawater intrusion and freshening in Soc Trang Province [15] or acidic groundwater [16]; groundwater quality in Ca Mau still remains unknown. Therefore, this study aims to investigate the suitability of groundwater quality for drinking and irrigation practices for the Ca Mau province. The information will contribute to help decision makers, planner and users in preparing appropriate water treatment techniques and protection measures for groundwater resource in the area.

2. Study area

Ca Mau is a coastal province in the Vietnamese Mekong Delta and locate in the south most part of Vietnam. The study area is a peninsula, bound by Gulf of Thai Lan in the west and East Sea in the east. The province area is about 5,300 km^2 and population of 1.4 million people. The area elevation varies from 0 to 2m. Therefore, the area is susceptible to climate change and sea level rise. Climate has two distinct seasons: the rainy season starts from May to October and the dry season lasts from November to April in the following year. According to monitoring data in Ca Mau province from 2015 to 2017, annual rainfall is about 2140 mm and 91% of the total annual rainfall observed in rainy season. Surface water in the area controlled by dense canal and tidal regime. The land use in the area is mostly for agricultural and aquacultural practices.

Due to climate change, dam construction in the upstream part of Mekong Delta, expansion of shrimp farms, water resources are facing with many challenges including seawater intrusion, contamination, and severe droughts. Due to poor quality, surface water is generally not used for drinking water and industrial works. No surface water is available in cannel systems. Water supply in the area is mostly dependent on groundwater resource. Groundwater even uses for irrigation and dilution of saltwater in shrimp farm illegally, in particularly in the dry weather.

The area has 7 confined aquifers, namely Holocene (qh), Upper Pleistocene (qp^3), Upper-middle Pleistocene (qp^{23}), lower Pleistocene (qp^1), middle Pliocene (n_2^2), lower Pliocene (n_2^1) and Upper Miocene (n_1^3). According to hydrogeological investigation of DWRPIS [12], average of hydraulic conductivity values of qp^3 aquifer k= of 27.8 m/day and k=20.4 m/day for $qp^{2,3}$, K= 18 m/day for qp1, K = 22.4 m/day for n_2^2, K = 17.5 m/day for n_2^1. Total 175,000 wells installed in aquifer systems and groundwater abstraction rate is about 430,000 m^3/day. The highest abstraction volume is observed in aquifer qp23 (~224,000 m^3/day). The aquifer qp_1, n_2^2, n_2^1, groundwater abstraction rates are 92,000, 107,000 and 3,000 m^3/day, respectively. Groundwater abstraction rate in Holocene and Upper Pleistocene are negligible due to saline groundwater. Due to very deep below surface, not many groundwater abstraction wells were installed in n_2^1 and n_1^3 aquifers.
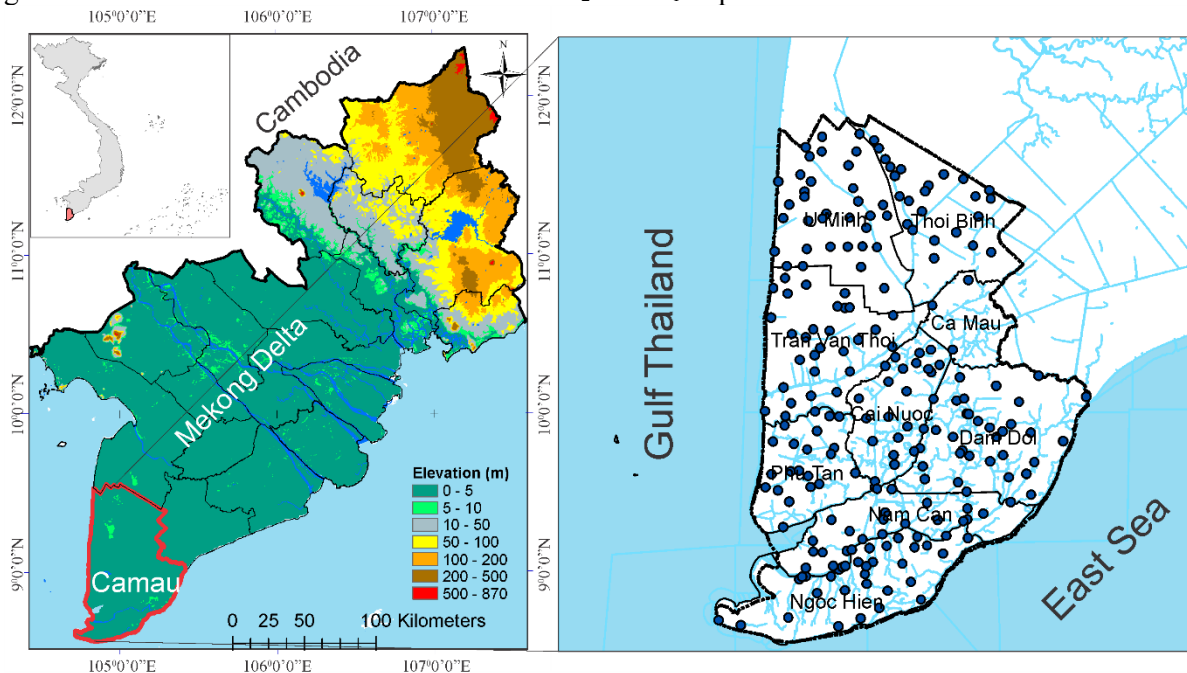

Figure 1. Location of Ca Mau plotted on topography map and groundwater sampling area

3. Method

3.1. Dataset

The study utilized the dataset of about 246 groundwater samples collected from 224 abstraction wells during 2013-2016 in Mekong Delta. The groundwater samples were collected by Division for Water Resources Planning and Investigation for the South of Vietnam (DWRPIS, [12]). Among 224 investigated wells, groundwater samples were doubly collected from 22 selected wells for Quality Assurance (QA) of sampling and chemical analysis. The groundwater samples were taken by submersible pump that install directly in the wells. The private wells are pumped every day for water consumption of local people. Water in the wells were pumped out about 10 min, before sampling. The samples were analyzed after sampling by Division for Water Resources Planning and Investigation for the south of Vietnam following water National Water Chemical Analysis Standards for Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, SO_4^{2-}, Cl^-, HCO_3^-, NO_3^-, and NO_2^-.

3.2. Drinking water assessment

This study applied GWQI method for drinking water evaluation. Calculation of GWQI was based on TDS, pH, K^+, Ca^{2+}, Na^+, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-} and NO_3^-. The weight of each ion for calculating the GWQI was assigned according to their relative importance on drinking water quality and human health. The weight normally assigned by local expert's opinions; therefore, it is difficult for comparison of the GWQI in global scale. To overcome this issue, this study will summaries weight values from previous studies to generate the general values for the area (Table 1).

Table 1. Weight of each ion for GWQI calculation in previous studies

Chemical parameter	India				Iran	Bangladesh	Ghana	Pakistan	Turkey	This study
	[17]	[18]	[19]	[7]	[20]	[21]	[22]	[23]	[24]	
pH	4		5	4	3	4	4	4	4	4
TDS	4	5	5	5	3	4	5	4	5	5
TH	4			2						4
Ca^{2+}	2	3	2	3	3	2	3	2	3	3
Mg^{2+}	2	3	2	3	3	2	3	2	3	3
Na^+	4	4	4		4	3		3	4	4
K^+	1	2	1		2	2		2	2	2
HCO_3^-	1	1	3	1	1	1	1	3	1	2
Cl^-	5	5	4	5	5	3	5	4	5	4
SO_4^{2-}	5	5	5	4	5	4	5	5	5	5
NO_3^-	5	5	5	5	5	5	5	5	5	5

The relative weight for each ion was calculated as per Eq. (2)

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (1)$$

Where, Wi, wi and n represent the relative weight, the weight for each ion and the number of ions to be evaluated, respectively.

The quality rating scale (qi) for each ion was calculated as equation:

$$q_i = \frac{C_i}{S_i} \, x \, 100 \qquad (2)$$

Where, Ci and Si represent the actual concentration of each ion and their concentration in drinking water limit (DWL) recommended by WHO [3], respectively.

Table 2. General groundwater chemistry and standard values for drinking water

Parameter	Mean	SD	Min	Max	DWL [3]	No of sample exceeded DWL
pH	8.1	0.4	6.8	9.2	6.5-8.5	23
TDS (mg/L)	991.6	529.2	202.0	3210.7	1000.0	85
Na^+(mg/L)	278.5	168.3	51.2	833.3	200.0	134
TH (mg/L $CaCO_3$)	193.7	170.7	10.0	1164.8	300.0	35
K^+ (mg/L)	12.8	7.3	1.3	58.6	no limit listed	
Ca^{2+} (mg/L)	29.0	26.1	2.0	245.5	75.0	10

Parameter	Mean	SD	Min	Max	DWL [3]	No of sample exceeded DWL
Mg^{2+} (mg/L)	29.4	28.0	1.2	182.4	50.0	33
NH_4^+ (mg/L)	0.47	0.70	0.00	3.68	3.0	5
Fe (mg/L)	0.10	0.11	0.00	0.53	0.3	15
HCO_3^- (mg/L)	516.2	158.9	91.5	870.1	120.0	223
Cl^- (mg/L)	227.9	260.3	4.3	1262.0	250.0	74
SO_4^{2-} (mg/L)	51.7	62.2	0.0	499.4	250.0	4
NO_3^- (mg/L)	6.6	5.3	0.0	40.4	50.0	0

The sub index SI value was calculated for each ion as equation below:

$$SI_i = W_i \, x \, q_i \qquad (3)$$

The GWQI value is calculated by

$$GWQI = \sum_{i=1}^{n} SI_i \qquad (4)$$

The standards of classifying drinking water quality in terms of GWQI are shown on Table 3

Table 3. Classification of groundwater quality

Water index	Index values	Water condition	No samples	Percentage
Drinking				
Groundwater quality index (GWQI)	<50	Excellent	19	7%
	50-100	Good	176	63%
	100-200	Poor	77	28%
	200-300	very Poor	5	2%
	>300	Unsuitable	2	1%
Irrigation				
Sodium Adsorption Ratio (SAR)	<10	Excellent	153	55%
	10-18	Good	86	31%
	18-26	Doubtful	33	12%
	>26	Unsuitable	6	2%
Sodium percentage (Na%)	<20	Excellent	0	0%
	20-40	Good	12	4%
	40-60	Permissible	47	17%
	60-80	Doubtful	99	36%
	>80	Unsuitable	120	43%
Permeability index (PI)	>75	Suitable	239	86%
	25-75	Good	40	14%
	<25	Unsuitable	0	0%
Magnesium Hazard (MH)	<50%	Suitable	128	46%
	>50%	Unsuitable	150	54%

3.3. Irrigation water assessment

The chemical composition of irrigation water directly impacts on plants yield in terms of toxicity/deficiency or indirect by changing nutrient availability. Previous studies proposed various indicator for assessment of irrigation water.

Sodium percent (Na%)

$$Na\% = \frac{Na^+}{Ca^{2+}+Mg^{2+}+Na^++K^+} \text{x}100 \text{ (concentration of parameters meq/l)}$$

Sodium adsorption ratio (SAR)

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}\text{x}100$$

Permeability index

$$PI = \frac{Na^++\sqrt{HCO_3^-}}{Ca^{2+}+Mg^{2+}+Na^+}\text{x}100$$

According to Doneen (1964), PI can be categorized in three classes: class I (>75%, suitable), class II (25–75%, good) and class III (<25%, unsuitable). Water under class I and class II are recommended for irrigation.

Magnesium hazard

$$MH = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}}\text{x}100$$

According to this, high magnesium hazard value (50 %) has an adverse effect on the crop yield as the soil becomes more alkaline.

4. Results and discussion

4.1. General groundwater characteristic

General characteristics of groundwater chemistry in Ca Mau Province is shown on Table 2. Groundwater pH ranges from 6.75 to 9.18, and 8.06 in average indicating that chemical characteristic of the groundwater samples is neutral to alkaline. The drinking water pH values are recommended within the range of 6.5–8.5 [3]. TDS ranges from 202 to 8089 mg/L, about 36% of total groundwater samples show TDS greater than 1000 mg/L (Drinking Water Limit; [3]).

The ionic dominance trend for cations was $Na^+ > Mg^{2+} > Ca^{2+} > K^+$, while $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > NO_2^-$ for anions. The mean concentrations of sodium and bicarbonate were the highest among all the cations and anions, respectively. The sodium and bicarbonate ions were widely dispersed in groundwater, which might be generated by weathering and cation exchange occurred by freshening process the coastal aquifers. Na^+ has concentration levels of 51 to 1,280 mg/L (average of 280 ± 175). The maximum Na^+ concentration in drinking water is 200 mg/L according to guidelines of WHO [3]. About 61% of groundwater samples have Na^+ concentration exceeding the drinking water guidelines. Sodium is important for human body. However, drinking of high sodium concentration in water may be cause adverse impacts on human health problems such as hypertension, heart disease or kidney for some people.

The concentration of Ca^{2+}, and Mg^{2+} were 29.5 and 32.4 mg/L in average, respectively. Generally, there is no limitation for Ca and Mg concentration in drinking water. High contents of Ca^{2+} and Mg^{2+} may be good for human healthy. However, high concentration of Ca^{2+} and Mg^{2+} induce high in total hardness. Hard water is generally not harmful to human health but can create serious problems in industrial settings. Calcium and magnesium carbonates precipitation on the surfaces of pipes and the surfaces of heat exchangers can reduce the effective function of machine and clogging of pipeline. Water hardness can even cause breaks in equipment that handles water such as boilers, cooling towers. The hardness of water is also suggested as the cause of the non-formation of soap suds and making difficulties in cleaning and laundering. In the study area, groundwater hardness varied from 10 to 1164.8

mg/L (as $CaCO_3$ concentration) and 193.7 mg/L in average. About 16% of groundwater samples even have hardness greater than recommended for drinking water (300 mg/L; [3]).

K^+ is a necessary element for the human body, no recommendation for K concentration in drinking water. Fe and NH_4^+ concentrations are up to 0.5 and 11 mg/L, respectively. Generally, the Fe and NH_4^+ concentration in drinking water will not induce health risks, but they can cause laundry problems and smelly due to iron precipitation and high NH4. The concentration of Fe and NH_4^+ in drinking water are suggested for 0.3 and 3 mg/L, respectively.

Among all anions in groundwater samples, the mean and standard deviation concentrations of HCO_3^-, Cl^-, SO_4^{2-}, NO_2^-, NO_3^-, were found at 515±150, 240±380, 54.8±80.7, 1.77±3.42, and 5.86±5.22 mg/L, respectively. About 31 and 2% of groundwater samples have Cl^- and SO_4^{2-} concentrations are greater than those values in DWL for 250 mg/L for Cl and SO4 [3]. Even though NO_3 concentrations is up to 40.4 mg/L, smaller than the maximum concentration of 50 mg/L recommended for drinking water by WHO (2011), the NO_3 concentration are much higher than observed NO3 in groundwater from others province in the Mekong Delta. According to data from National Groundwater Monitoring Network for southern Vietnam [13], NO_3 concentration was generally low or not detected in Long An, Tra Vinh, An Giang, Ben Tre, Vinh Long and Dong Thap. The high NO_3 concentrations are normally observed high in Ho Chi Minh City, Tay Ninh, Binh Duong and Dong Nai due to high permeable of surface sediment [14]. Unconfined aquifers are generally susceptible to NO_3 contamination [25]. However, the aquifer in Ca Mau is mostly confined, aquifer is protected by thick clay layers [12]. Therefore, observation of high NO_3 concentration is very abnormal. The NO_3 may be introduced from upper part through well casing or other pathways to deep aquifers [16]. However, finding the origin of NO_3 in groundwater of this area is beyond scope of this study, it needs to have further investigation.

Generally, the contamination of TDS, TH, Na and Cl was the most concern in the groundwater of Ca Mau Province. The high concentration of TDS, Cl is observed in coastal areas such as Nam Can, Phung Hiep, Tran Van Thoi, Cai Nuoc, and U Minh may relate to saltwater intrusion (Figure 2). The groundwater samples have Na concentration exceeding that value in DWL observed in most part of province except Thoi Binh and Ca Mau City. In contrast, the extremely hardwater observed mainly in Tran Van Thoi and U Minh districts.
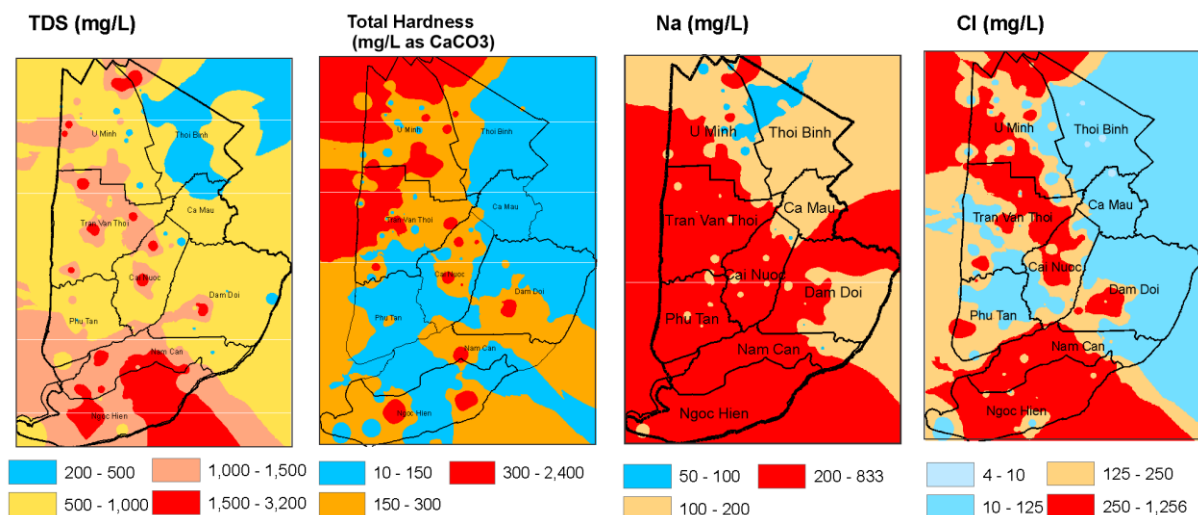

Figure 2. Spatial distribution of TDS, TH, Na and Cl concentration in groundwater

4.2. Drinking water assessment

As mentioned above groundwater quality index is widely applied for evaluation of groundwater quality for drinking purpose. Calculated GWQI values in this study range from 25.2 to 585 (average of 87.9). The groundwater quality belongs 4 groups including good, poor, very poor and unsuitable quality for drinking purpose. About 31% of groundwater samples show poor to unsuitable groundwater quality and mostly observed in south and western part of the study area (Figure 3). The high GWQI is associated to

high TDS, Cl and Na concentrations suggesting salinisation is the main cause of deterioration of groundwater quality.
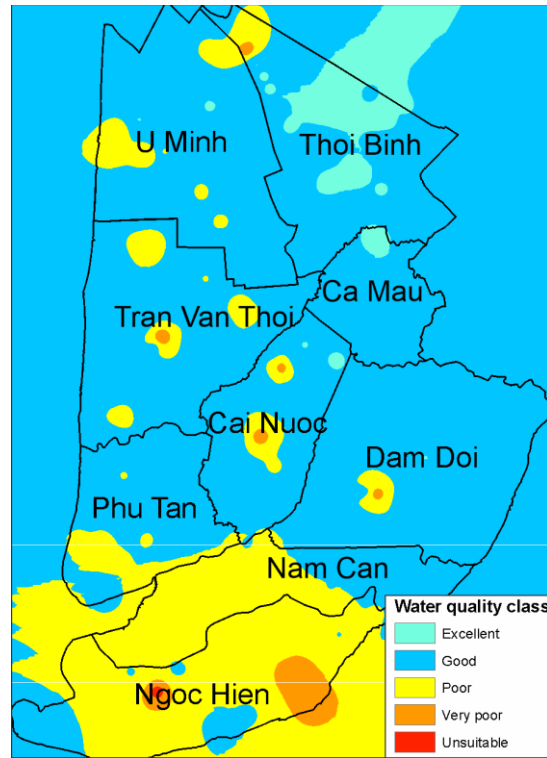

Figure 3. Groundwater quality map of Ca Mau Peninsula

4.3. Irrigation water assessment

Higher salinity will reduce the osmotic activity of plants and prevent water from reaching the branches and leaves of plants, resulting in inferior production [4,5]. Electricity conductivity (EC) is a typical measurement of salinity. In general, EC should be less than 2250 uS/cm in irrigation water. Higher concentration of sodium in irrigation water will affect the soil permeability and make the texture of soil hard to plough. SAR and %Na are good measures of alkali/sodium hazard to crops. Na% should be lower than 60 % in irrigation water, and SAR lower than 18 is suitable for irrigation water but may be acceptable if it is lower than 26. The results listed in Table 1 show that the SAR values of all samples vary from 1.2 to 29.6. Only 6 samples show SAR greater than 26, they are in high saline groundwater zone. According to PI index, all groundwater samples can be used for irrigation. In contrast, about 78% of groundwater samples have Na% greater than 60, indicating unsuitability of groundwater for irrigation. According to MH index only 46% of groundwater can be used for irrigation.

5. Conclusion

Groundwater in Ca Mau province is facing with high TDS, TH, Na and Cl concentrations. 61 % of samples show exceeded Na concentration for drinking water. Overall, about 31% of groundwater samples in the area were classified into poor and unsuitable for drinking purpose. High TH level in groundwater may also indue problems for industrial and domestic uses. For irrigation, even though groundwater quality is suitable for irrigation according to SAR and PI index, the 79% and 54% of groundwater samples are unsuitable for irrigation by Na% and MH index, respectively. This finding suggest that groundwater needs to be treated before using. Additionally, over exploitation of groundwater in this area is known as the underlying cause for land subsidence and contamination. Therefore, there is the need for seeking alternative water sources for water supply, especially in coastal areas.

Acknowledgement

References

[1]   Appelo, C.A.J. and Postma, D. 2004 Geochemistry, groundwater and pollution. CRC press.

[2]   Ferguson, G. and Gleeson, T., 2012. Vulnerability of coastal aquifers to groundwater use and climate change *Nature Climate Change* **2**(5) 342-345.

[3]   WHO 2011 Guidelines for Drinking-Water Quality, 4th ed World Health Organization, Geneva, Switzerland

[4]   Yasuor, H., Yermiyahu, U. and Ben-Gal, A. 2020 Consequences of irrigation and fertigation of vegetable crops with variable quality water: Israel as a case study. *Agricultural Water Management* **242** 106362.

[5]   Che, Z., Wang, J. and Li, J. 2021 Effects of water quality, irrigation amount and nitrogen applied on soil salinity and cotton production under mulched drip irrigation in arid Northwest China *Agricultural Water Management* **247** 106738.

[6]   Uddin, M.G., Nash, S. and Olbert, A.I., 2021. A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators* **122** 107218.

[7]   Verma, P., Singh, P.K., Sinha, R.R. and Tiwari, A.K. 2020 Assessment of groundwater quality status by using water quality index (WQI) and geographic information system (GIS) approaches: a case study of the Bokaro district, India *Applied Water Science* **10**(1) 1-16.

[8]   Amiri, V., Kamrani, S., Ahmad, A., Bhattacharya, P. and Mansoori, J. 2021 Groundwater quality evaluation using Shannon information theory and human health risk assessment in Yazd province, central plateau of Iran *Environmental Science and Pollution Research* **28**(1) 1108-1130.

[9]   El Baba, M., Kayastha, P., Huysmans, M. and De Smedt, F. 2020 Evaluation of the groundwater quality using the water quality index and geostatistical analysis in the Dier al-Balah Governorate, Gaza Strip, Palestine *Water* **12**(1) 262.

[10]   Bangia, K., August, L., Slocombe, A. and Faust, J. 2020 Assessment of contaminants in California drinking water by region and system size *AWWA Water Science* **2**(5) e1194.

[11]   Bui, T.V., Dang, T.L., and Le, T.M.V. 2015 Groundwater issues and hydrogeological survey of the Mekong River basin in Vietnam. In: Ha, K., Nguyen, T.M.N., Lee, E., and Jayakumar, R. (Eds.), Current Status and Issues of Groundwater in the Mekong River Basin. KIGAM-CCOP-UNESCO Bangkok Office, pp. 93–121.

[12]   Pham, K.T., Nguyen, T.H., Vu, B.M., Nguyen, V. N., Dang, V.T., Cao, X.V. 2019 Groundwater assessment and investigation in Vietnamese Mekong Delta Key economic region. Division for Water Resources Planning and Investigation for the South of Vietnam.

[13]   Minderhoud, P.S.J., Erkens, G., Pham, V.H., Bui, V.T., Erban, L., Kooi, H. and Stouthamer, E., 2017. Impacts of 25 years of groundwater extraction on subsidence in the Mekong delta, Vietnam. *Environmental Rresearch Letters* **12**(6) 064006.

[14]   Ha, Q.K., Kim, K., Phan, N.L., Phung, T.H., Lee, J., Nguyen, V.K. and Phan, C.N. 2019 A hydrogeological and geochemical review of groundwater issues in southern Vietnam *Geosciences Journal* **23**(6) 1005-1023.

[15]   Ha, Q.K., Le Vo, P., Phan, C.N., Pham, V.H. and Nguyen, V.K. 2021 Identification of freshwater-saltwater interface in coastal areas using combination of geophysical and geochemical methods: A case study in Mekong Delta, Vietnam *IOP Conference Series: Earth and Environmental Science* **652** 012006.

[16]   Ha, Q.K., Choi, S., Phan, N.L., Kim, K., Phan, C.N., Nguyen, V.K. and Ko, K.S. 2019 Occurrence of metal-rich acidic groundwaters around the Mekong Delta (Vietnam): A phenomenon linked to well installation. *Science of the Total Environment* **654** 1100-1109.

[17] Adimalla, N. 2019 Controlling factors and mechanism of groundwater quality variation in semiarid region of South India: an approach of water quality index (WQI) and health risk assessment (HRA). *Environmental Geochemistry and Health* 1-28.

[18] Vasanthavigar, M., K. Srinivasamoorthy, K., Vijayaragavan, K. Rajiv Ganthi, R., Chidambaram, S., Anandhan, P., Manivannan, R. and Vasudevan, S. 2010 Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India *Environmental Monitoring and Assessment* **171**(1) 595-609.

[19] Rao, N.S., Sunitha, B., Rambabu, R., Rao, P.N., Rao, P.S., Spandana, B.D., Sravanthi, M. and Marghade, D. 2018 Quality and degree of pollution of groundwater, using PIG from a rural part of Telangana State, India. *Applied Water Science* **8**(8) 1-13.

[20] Abbasnia, A., Yousefi, N., Mahvi, A.H., Nabizadeh, R., Radfard, M., Yousefi, M. and Alimohammadi, M. 2019 Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: Case study of Sistan and Baluchistan province (Iran). *Human and Ecological Risk Assessment: An International Journal* **25**(4) 988-1005.

[21] Islam, A.R.M.T., Siddiqua, M.T., Zahid, A., Tasnim, S.S. and Rahman, M.M. 2020 Drinking appraisal of coastal groundwater in Bangladesh: An approach of multi-hazards towards water security and health safety *Chemosphere* **255**126933.

[22] Boateng, T.K., Opoku, F., Acquaah, S.O. and Akoto, O. 2016 Groundwater quality assessment using statistical approach and water quality index in Ejisu-Juaben Municipality, Ghana *Environmental Earth Sciences* **75**(6) 1-14.

[23] Khanoranga and Khalid, S. 2019 An assessment of groundwater quality for irrigation and drinking purposes around brick kilns in three districts of Balochistan province, Pakistan, through water quality index and multivariate statistical approaches *Journal of Geochemical Exploration*, **197** 14-26.

[24] Varol, S. and Davraz, A., 2015. Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey) *Environmental Earth Sciences* **73**(4) 1725-1744.

[25] Chae, G.T., Kim, K., Yun, S.T., Kim, K.H., Kim, S.O., Choi, B.Y., Kim, H.S., and Rhee, C.W. 2004 Hydrogeochemistry of alluvial groundwaters in an agricultural area: an implication for groundwater contamination susceptibility *Chemosphere* **55** 369–378.